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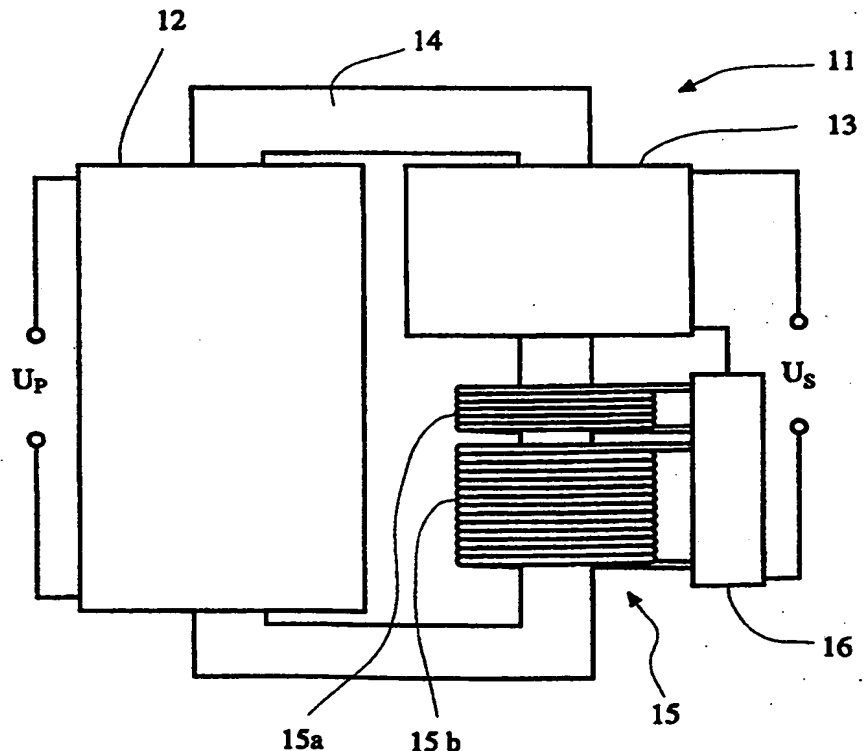
## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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(54) Title: TRANSFORMER WITH VOLTAGE REGULATING MEANS

## (57) Abstract

A power- or regulating transformer (11) with voltage regulating means is disclosed. The transformer comprises regulating windings (15) made of a flexible conductor having electric field containing means forcing the electric field due to the electric current in the winding to be contained within the flexible conductor. Since virtually no electric field is to be found outside the flexible conductor of the regulating winding (15), the regulating winding may be formed without having to consider the electric field distribution, thus providing for a transformer with a favorable regulating winding design.



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Transformer with voltage regulating means

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## TECHNICAL FIELD

10 The present invention relates to a power- or regulating transformer, with voltage regulating means, in a power generation, transmission or distribution system with a rated power ranging from a few hundred kVA up to more than 1000 MVA and with a rated voltage ranging from 3-4 kV and up to very high transmission voltages, 400 kV to 800 kV or higher. More specifically the invention relates to regulating windings in said power- or regulating transformer.

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## BACKGROUND OF THE INVENTION

20 The primary task of a power transformer is to act as an electric "gear box", allowing electric energy to flow from one electrical system to another. The electrical systems interconnected with a transformer usually have different voltages but the same frequency. The power transformer, in its simplest form, comprises only two types of windings, a primary winding and a secondary winding. The transformation ratio is thereby fixed, that is, not possible to regulate. However, there is a need to be able to control the active and reactive power flow between the electrical systems in order to run systems in an efficient manner or, which is more fundamental, maintain the stability of the systems. Therefore, regulating means, comprising a regulating winding or windings, are often incorporated in the power transformer, or in a separate regulating transformer connected in series with the power transformer. These regulating transformers are sometimes referred to as "booster transformers". In order to obtain a flexible control over the electrical systems, the active and reactive power flow between the systems is preferably controlled independently of each other. In

order to achieve this, the phase-shift between the phase voltages of the systems must be able to be controlled with a variable angle.

In E. Wirth, J-F. Ravot: "Regulation transformers in power systems - new concepts and applications", ABB Review 4/1997, pp.12-20, a three-phase power transformer with integrated regulating means is described. The transformer has three core legs, each leg associated with phases U, V and W respectively. Around each leg a primary winding, a secondary winding, an in-phase control winding, a first quadrature control winding and a second quadrature control winding are wound. The in-phase control winding, the first quadrature control winding and the second quadrature control winding are all regulating windings. The in-phase control winding of each phase is, via a first tap changer common for all three phases, connected in series with the secondary winding of the same phase. This makes it possible to regulate the amplitude of the secondary voltage of each phase, that is, obtain in-phase regulation between the primary and secondary of the transformer. Via a second tap changer, also common for all three phases, the primary winding of phase U is connected in series with the first quadrature control winding of phase V and the second quadrature control winding of phase W. In a similar fashion the primary winding of phase V is connected in series with the quadrature control windings of phases W and U, and the primary winding of phase W is connected in series with the quadrature control windings of phases U and V. The arrangement of the quadrature control windings and the second tap changer is such, that the voltage across the series connected quadrature windings always is perpendicular to the voltage across the primary winding. The requirements for so called quadrature regulation is therefore fulfilled. The phase angle of the primary voltage of each phase can thus be regulated by means of the second tap changer. By combining the in-phase regulation on the secondary side with the quadrature regulation on the primary side of the transformer, it is possible to, for each phase, phase shift the voltage across the transformer and thus accomplish an independent active and reactive power flow control between the primary and secondary side of the transformer.

In N. Mohan: "MPTC: An economical alternative to universal power flow controllers", EPE 97 in Trondheim, pp. 3.1027-3.1032, another regulation system to control the power flow is described. It consists of a three phase regulating transformer where fractions of the primary voltages, by means of secondary windings and via thyristor bridge arrangements, are injected in series with each

phase voltage. The secondary windings thus act as regulation windings. By controlling the switches in the thyristor bridges, a linear combination of the voltages over the secondary windings can be added to each phase voltage and each phase voltage can thus be phase-shifted by a variable angle.

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The regulating means of the three phase transformer by E. Wirth, J-F. Ravot described above, consist of nine regulating windings, three per phase, and two tap changers. The regulating means of the regulating transformer by N. Mohan, consist of one regulating winding and one thyristor bridge per phase, totalling three regulating windings and three thyristor bridges. Depending on the regulating voltage, the space occupied by the regulating windings may be quite large due to insulation requirements.

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## 15 SUMMARY OF THE INVENTION

Irrespectively of whether the regulating windings are incorporated in a power transformer or in a regulation transformer, it is technically and economically favourable to reduce the space occupied by the regulating windings. The objective of the invention is to provide a transformer in which the regulating windings display a compact design. This objective is achieved by a transformer where at least one of the regulating windings at least partly comprises a flexible conductor having electric field containing means.

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An example of such a flexible conductor with field containing means, is a flexible cable of the sort used for power distribution. Such a cable comprises a conducting core, a first semiconducting layer provided around said conducting core, a solid insulation layer provided around said first semiconducting layer and a second semiconducting layer provided around said insulation layer. On the condition that the second semiconducting layer is grounded, the cable has the ability to, within itself, contain the electric field arising from the current in the conducting core. The electric stress is thus absorbed within the solid insulation of the cable and there is virtually no electric field outside the second semiconducting layer. In the cable the different layers are firmly attached to each other. Also, the solid insulation layer and the semiconducting layers are made of materials which have almost the same coefficient of expansion. The cable can therefore be subjected to considerable mechanical and thermal stress without the layers

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separating from each other, forming cavities in-between the layers. This is an important feature, since partial discharges will appear in a cavity if the electric field stress exceeds the dielectric strength of the gas in the cavity. It is especially important that the first semiconducting layer and the solid insulation layer is  
5 firmly attached to each other since the electric field stress is largest in this part of the cable. A cable similar to the sort presented above is described in PCT applications WO-97/45847 and WO-97/45921.

10 The invention will now be described more fully with reference to the appended drawings.

#### BREIF DESCRIPTION OF THE DRAWINGS

15 Fig. 1 is a schematic figure of a first embodiment of the invention illustrating the principle of the invention.

Fig. 2 shows an example of a flexible conductor used in a transformer according to the invention.

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Fig. 3 is a schematic illustration of a second embodiment of the invention.

#### DETAILED DESCRIPTION OF THE INVENTION

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A first embodiment of the invention, a single-phase transformer 11 with voltage regulation means for voltage control, is schematically shown in fig. 1 in order to illustrate the principle of the invention. A primary winding 12 and a secondary winding 13 are wound round a transformer core 14. The regulating  
30 means comprises a regulating winding 15 that is wound round the core 14 and a tap changer 16. The regulating winding 15 is divided into two regulating winding parts 15a, 15b, each being connected to the tap changer 16. The secondary winding 13 is via the tap changer 16 connected in series with the regulating winding 15. The transformer 11 interconnects two electrical systems, one with a  
35 voltage level corresponding to the primary voltage  $U_p$  and one with a voltage level corresponding to the secondary voltage  $U_s$ . By means of the tap changer 16 and the regulating winding parts 15a, 15b, the secondary voltage  $U_s$  can be

adjusted in discrete voltage levels and thus the transformer ratio  $U_p/U_s$  can be regulated.

In a conventional transformer, transformer oil is usually used to insulate the windings from each other and from the transformer core. In PCT application WO-97/45847, a transformer where the primary and secondary windings are made of a flexible conductor with electric field containing means is presented. An example of a flexible conductor in the form of a cable of the sort presented in WO-97/45847 is shown in fig. 2. The cable 21 comprises at least one conductor 22 with a first semiconducting layer 23 disposed around said conductor 22. On the outside of this first semiconducting layer 23 is the main insulation of the cable in the form of a solid insulation 24, and surrounding said solid insulation 24 is a second semiconducting layer 25. On the condition that the second semiconducting layer 25 is grounded the cable has the ability to, within itself, contain the electric field arising from the current in the conductor 22. The electric stress is thus contained within the solid insulation 24 of the cable and there is virtually no electric field outside the second semiconducting layer 25.

A flexible conductor with electric field containing means, for example of the sort shown in fig. 2, is used in the regulating winding of the regulating transformer shown in fig. 1. Since no electric field is to be found outside the flexible conductor of the regulating winding 15, the winding may be formed without having to consider the electric field distribution. A technically favorable design is thus achieved. The primary winding 12 and the secondary winding 13 are also made of a flexible conductor having electric field containing means and thus no transformer oil is needed for insulation. If, in addition, the tap changer 16 is e.g. of the electronic or air insulated type, oil in the transformer can be avoided altogether, which is economically as well as environmentally favorable.

In fig. 3 a second embodiment of the invention is schematically illustrated. It is a three-phase regulating transformer 31 with voltage regulating means which provide phase angle regulating possibilities between the input and output side of the transformer. The transformer 31 connects a first electrical system with phase voltages  $U_A, U_B, U_C$  to a second electrical system with phase voltages  $u_A, u_B, u_C$ . The transformer 31 comprises three core legs 32a, 32b, 32c made of a magnetizable material. On each core leg, a primary winding 33 and a regulating winding 34 is wound. Normally the windings on each core leg are wound one outside the other.

For clarity reasons however, the windings on each core leg in fig. 3 are shown one after the other. The primary winding 33 and the regulating winding 34 on each core leg 32 are made of a flexible conductor with electric field containing means 35. The said conductor 35 may for example be a cable of the sort described in fig. 2. The regulating windings 34 are divided into a number of regulating winding parts. Each regulating winding part is, by means of the same flexible conductor that forms the regulating winding part, connected to a switching unit 36. For clarity reasons this connection is, in fig. 3, only shown for the regulating winding 34c of one the core legs 32c. However, the regulating winding parts of the regulating windings 34a, 34b of the other two core legs 32a, 32b are connected to the switching unit 36 in the same fashion. Each regulating winding 34 is divided into an appropriate number of regulating winding parts. Preferably, the regulating winding parts on each core leg have turn ratios following  $1:3:9 \dots 3^{N-1}$ . In the switching unit 36, the regulating winding parts are connected to an electronic switch system. Via said switch system, suitable combinations of the regulating winding parts are connected in series to obtain the desired phase voltages  $u_A$ ,  $u_B$ , and  $u_C$ . With the arrangement it is possible to phase-shift the phase voltages  $u_A$ ,  $u_B$ , and  $u_C$  compared to  $U_A$ ,  $U_B$ , and  $U_C$  up to  $\pm 60^\circ$ . By performing a series of phase-shifting operations, one after the other, it is possible to shift the voltages  $u_A$ ,  $u_B$ , and  $u_C$  a whole  $360^\circ$ . By continuously performing phase-shifting operations, it is possible to link two asynchronous electric systems with the same nominal frequency or systems with relatively small frequency differences.

Since each regulating winding 34 is made of a flexible conductor with electric field containing means 35, and since the electrical current in each regulating winding is led to the switching device also in a flexible conductor, the voltage regulating means of the transformer can be designed without having to consider the electric field distribution. The switching unit 36 can be placed close to, or even in physical contact with, the regulating windings 34. Alternatively, it is possible to place the switching unit 36 at a distance from the regulating windings 34 or indeed from the rest of the transformer, utilizing the same flexible conductors 35 that make up said windings 34 to connect the windings 34 to the switching unit 36. Since the primary windings 33 are also made of a flexible conductor having electric field containing means, the regulating transformer can be made oil-free which is economically as well as environmentally favorable.



The voltage regulating arrangement described above teaches how to use a flexible conductor in a winding in order to bring about a power or regulating transformer according to the invention. It is understood, however, that other power- or regulating transformer embodiments involving voltage regulating  
5 means comprising a flexible conductor with electric field containing means, are possible within the scope of the invention.

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## CLAIMS

1. A transformer with voltage regulating means comprising at least one regulating winding (15, 34), **c h a r a c t e r i z e d** in that any of the regulating windings (15, 34) at least partly comprises a flexible conductor having electric field containing means (35).
2. A transformer with voltage regulating means according to claim 1, **c h a r a c t e r i z e d** in that said flexible conductor (35) is made of a cable (21) comprising a conductor (22), a first layer (23) having semiconducting properties provided around said conductor (22), a solid insulation layer (24) provided around said first layer (23) and a second insulation layer (25) having semiconducting properties provided around said insulating layer (24).
3. A transformer with voltage regulating means according to claims 1-2, **c h a r a c t e r i z e d** in that the voltage regulating means provides phase-shifting capacity.
4. A transformer with voltage regulating means according to claims 1-3, **c h a r a c t e r i z e d** in that the transformer comprises an electronic tap changer.
5. A transformer with voltage regulating means according to claims 1-3, **c h a r a c t e r i z e d** in that the transformer comprises an mechanical air-insulated tap changer.
6. A transformer with voltage regulating means according to any of claims 1-5, **c h a r a c t e r i z e d** in that the transformer is oil-free.
7. A transformer with voltage regulating means according to claim 3, **c h a r a c t e r i z e d** in that that the phase-shift range is  $360^{\circ}$ .
8. A transformer with voltage regulating means according to claim 7, **c h a r a c t e r i z e d** in that the transformer connects two asynchronous systems with the same nominal frequency.

9. A transformer with voltage regulating means according to claim 7,  
c h a r a c t e r i z e d in that the transformer connects two electric systems  
with different nominal frequency.
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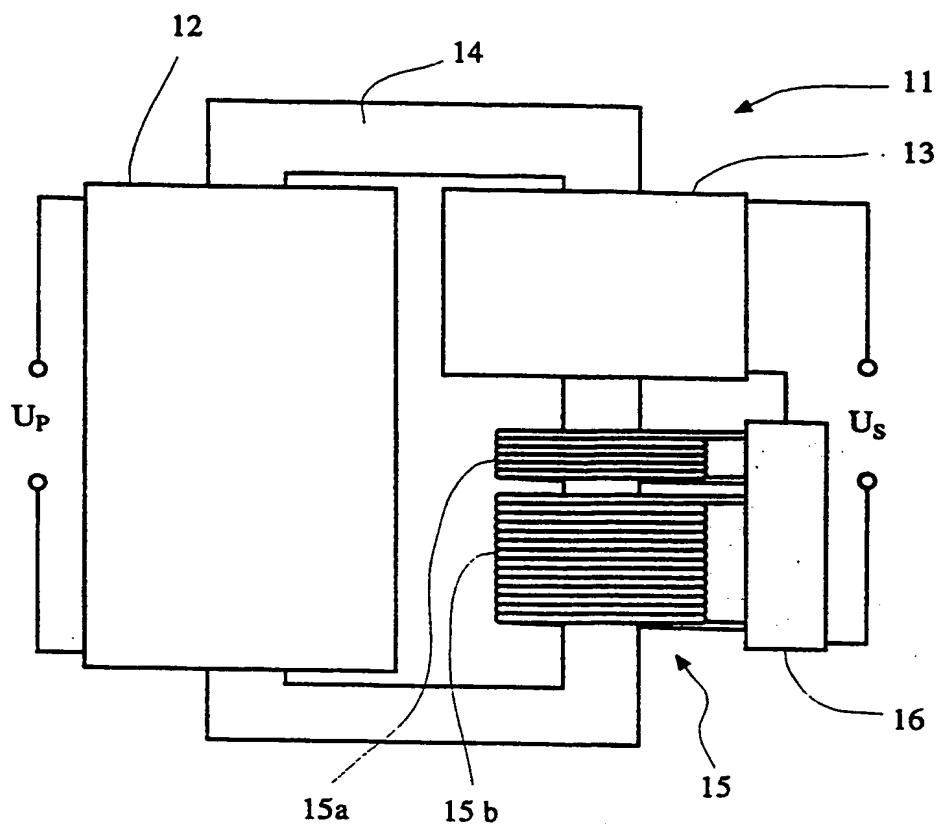


Fig. 1

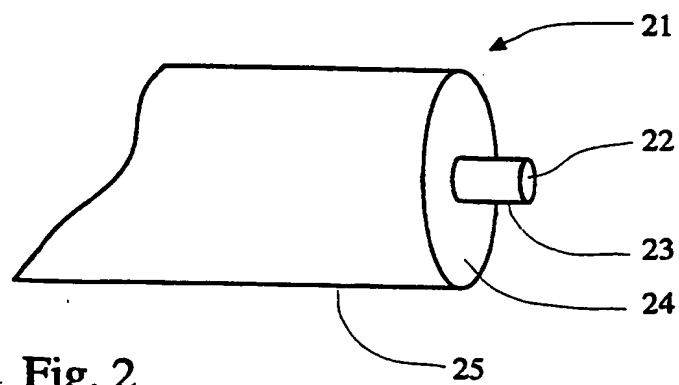


Fig. 2

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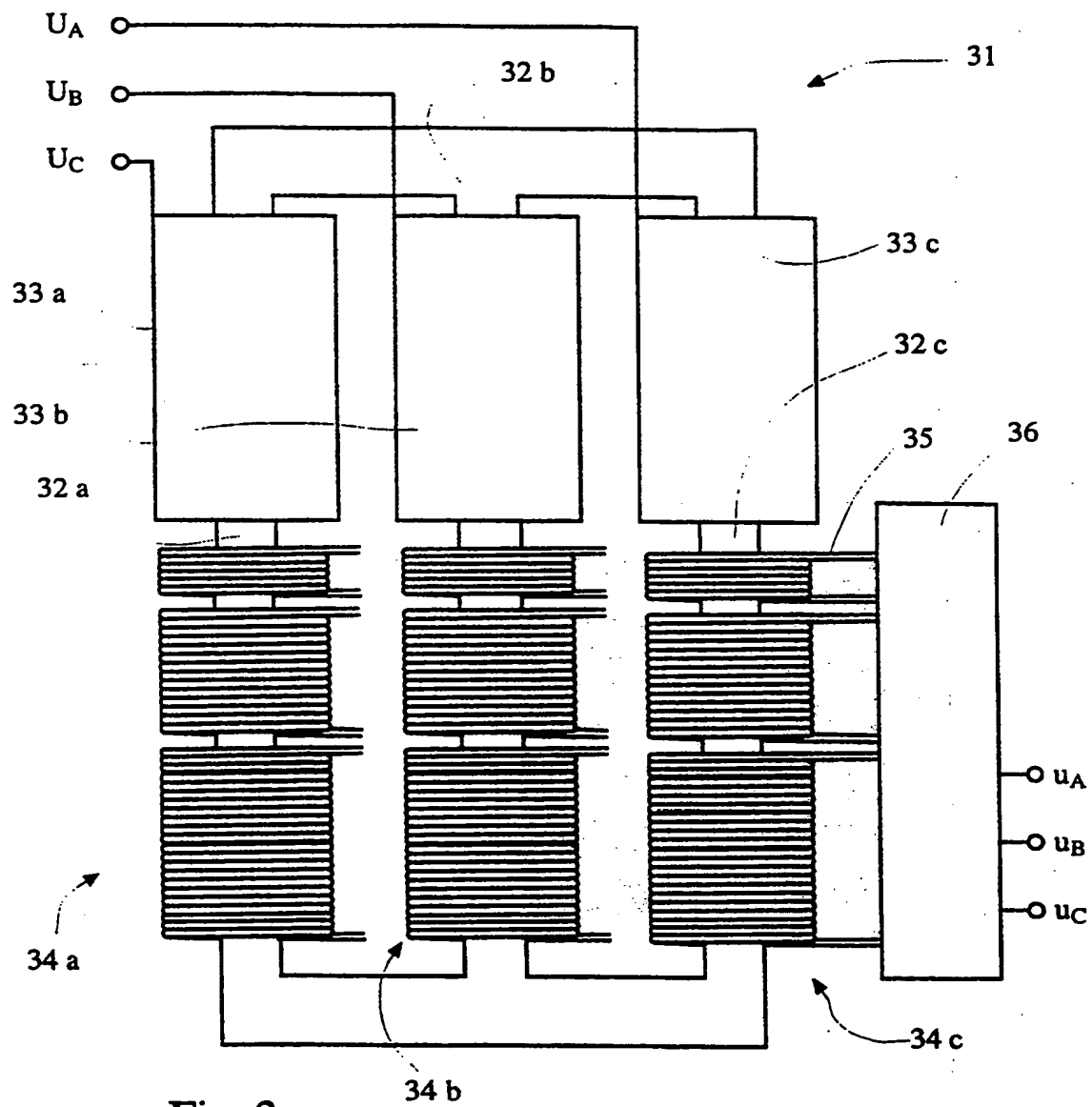


Fig. 3

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## INTERNATIONAL SEARCH REPORT

International application No.

PCT/SE 98/00151

## A. CLASSIFICATION OF SUBJECT MATTER

IPC6: H01F 29/00, H01F 27/32

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: H01F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EDOC, WPIL, JAPIO

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	GB 2018521 A (BBC BROWN, BOVERI & COMPANY LIMITED), 17 October 1979 (17.10.79), abstract  --	1
A	US 5036165 A (RICHARD K. ELTON ET AL), 30 July 1991 (30.07.91), abstract  -- -----	1

☐ Further documents are listed in the continuation of Box C.☒ See patent family annex.

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Information on patent family members

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International application No.

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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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